THREE LEVERS OF EMISSION CONTROL (3-LoEC)-MODEL: AT THE CORE OF GHG EMISSION-MANAGEMENT CONTROL SYSTEMS

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Abstract: *The Corporate Sustainability Reporting Directive (CSRD) requires from European enterprises to intensively engage in reporting and monitoring their sustainability related performance. Known as "climate-first" approach, fighting climate change has become the priority in politics. To contribute to that aim, companies face new regulations with a special focus on their greenhouse gas (GHG) emission performance. For the product specific measurement of GHG emissions, references are given to the methodology proposed in the established GHG Protocol Product Standard (GHG Protocol, 2011). In this standard the product's GHG emission – subsequently called "unit carbon footprint" (uCFP) – is measured via a generic activity-based methodology. Due to its deliberately generic definition, this methodology constitutes a conceptual model that contains no operationalization which is needed for practical implementations. In this paper this gap is closed by introducing the "3-Levers of Emission Control (3-LoEC)"-model, which has the following advantages: it measures the uCFP via three levers of emission control that are related to the consumption and procurement of energy, it is connected to data contained in activity-based costing (ABC) systems, and it is a forecasting instrument so that it is at the core of activity-based GHG emission budgeting and the corresponding management control system (MCS) with respect to GHG emission.*

Key words: greenhouse gas emission, carbon footprint, activity-based costing and budgeting, 3-Levers of Emission Control-model, management control system

1. INTRODUCTION

The CSRD requires certain European companies to apply new reporting standards from the financial year 2024 onwards. The ESRS comprise a set of individual standards that cover environmental, social and governance (ESG) matters, i.e. "topical standards", as well as cross-cutting reporting requirements. Over the next years, the number of ESRS that have to be applied will be extended constantly (Baumüller & Grbenic, 2021, p. 375). So far, only consultative versions of a first set of twelve standards are available, published by the EU Commission on June 9th, 2023 (European Commission, 2023a).

Out of all topical standards, the most concrete and extensive reporting requirements address environmental matters. This is arguably due to the fact that the scientific as well as political discourse is most advanced with regard to these matters, whilst social or governance matters are more difficult to formalize and to agree upon priorities. Within those environmental matters, however, there is again one standard that stands out in prominence: ESRS E1 on "climate change". The work on this standard has received most attention over the last years, which in turn reflects an "climate-first" approach that is the consequence of political priorities in the wake of Paris 2015 (HLEG on Sustainable Finance, 2018, p. 13). With regard to reporting, the ESRS oblige companies to measure these emissions, to report on actual emissions, on targeted reductions and on monitored achievements of the reduction objectives over time.

"*With regard to climate-related information, users are […] interested in the level and scope of GHG emissions and removals attributed to the undertaking, including the extent to which the undertaking uses offsets and the source of those offsets. […] Users are also interested to know the efforts made by companies to effectively reduce absolute GHG emissions as part of their climate mitigation and adaptation strategies, including scope 1, scope 2 and, where relevant, scope 3 emissions.*" (European Commission, 2022, rec. 47) For these purposes, the CSRD sets forth that companies shall refer to the accounting methodology developed by the GHG Protocol. ESRS E1 specifies, amongst other things, that "[…] *the undertaking shall disclose whether and how it has set GHG emissions reduction targets and/or any other targets to manage material climate-related impacts, risks and opportunities, for example, renewable energy deployment, energy efficiency, climate change adaptation, and physical or transition risk* *mitigation.*" (European Commission, 2023b, para. 34) Also, "*by reference to GHG emission reduction targets […], an explanation of the decarbonisation levers identified, and key actions planned, including changes in the undertaking's product and service portfolio and its adoption of new technologies*". (European Commission, 2023b, para. 16)

The referenced methodology from the GHG Protocol also encompasses a Product Life Cycle Accounting and Reporting Standard ("GHG Protocol Product Standard", GHG Protocol, 2011) for the product specific measurement of GHG emissions – subsequently called "unit carbon footprint" (uCFP). It is an activity-based measurement model. Furthermore, this activity-based uCFP, i.e. AB-uCFP measurement model is defined deliberately generically in order to allow different operationalizations for implementations. It only requires activity data to be multiplicatively connected with emission factors and global warming potential (GWP) factors. But there are many different possibilities of selecting activity data and corresponding emission and GWP factors. Furthermore, most companies have nowadays activity-based costing (ABC) systems in place. Hence, an alignment of the AB-uCFP measurement model with the ABC methodology would be beneficial for establishing a common and consistent information system for reporting, forecasting, managing and monitoring issues. The research problem addressed in this paper is the development of an adequate specification of the activity data and the emission and GWP factors for establishing an information system that integrates reporting as well as management issues for costing and carbon footprinting at the same time.

This research problem is an alignment problem as the specification of activity data and corresponding factors has to be aligned with the measurement methodology from the GHG Protocol Product Standard. Furthermore, the GHG Protocol measurement methodology constitutes a conceptual model due to its undefined operationalization specifications. Consequently, the alignment problem has to be solved by defining an adequate operationalization of the "conceptual GHG Protocol methodology" that allows its practical implementation within companies. For this purpose, an operationalized model will be designed that solves the research problem. The designed model – called "3-Levers of Emission Control (3-LoEC)"-model – specifies the activity data in terms of information contained in AB-costing systems and the factors in terms of publicly available information. This separation is guided by the special focus of the 3-LoEC model upon energy which is consumed in the company's activities and which has to be procured. Due to its origin in the GHG Protocol Product standard's measurement methodology it is automatically compliant with this methodology. Finally, the desired common and consistent information system foundation is established as the 3-LoEC-model uses information from the ABC system and as it is used for an activity-based measuring and forecasting the carbon footprint of the company's production domain what is needed for reporting and what is at the core of a GHG emission-MCS.

The structure of this paper is as follows: In the next section the GHG Protocol's key requirements on GHG emission measurement are identified and summarized concerning the emissions life cycle assessment (LCA) requirement and the requirement related to the activity-based emission measurement model. Subsequently, the design for the operationalization of the conceptual measurement model will be addressed and the developed design in form of the 3-LoEC-model is presented. Afterwards, the embedding of the 3-LoEC-model within a management information system (MIS) and its application within a GHG emission-MCS are demonstrated. Finally, the paper is concluded.

2. GHG PROTOCOL REQUIREMENTS: ACTIVTY-BASED GHG EMISSION MEASUREMENT

The conceptual GHG Protocol methodology requires the GHG emission measurement of the studied product over the product's life cycle. Concerning the measurement model to be applied, two approaches are possible, i.e. the direct physical emission measurement and the indirect measurement where the emission is calculated by multiplying activity data with emission and global warming potentials (GWP) factors. Due to the reference on activity data, the indirect model is an activity-based approach. It is the standard model applied in practical GHG measurement implementations, and this paper exclusively relies on this activity-based uCFP (AB-uCFP) model.

2.1. GHG Protocol Requirement: Life Cycle Assessment (LCA) of GHG Emission

In Chapter "*07 Boundary Setting*", *"Illustrate the product's life cycle process through a process map*" (GHG Protocol, 2011, p. 33) requires that the GHG emission not only is measured over all activities in the product's life cycle, which are summarized in five main process stages, but that the product's stages also are visualized. These requirements are conceptualized in Figure 1 via the activity diagram model that is expressed in the formal activity diagram modeling language of the unified modeling language UML (http://www.omg.org/spec/UML/). Of special interest in this modeling is that it contains the information objects (represented as rectangles) for the material and product flow next to the activities (represented as rounded rectangles) for the five stages in the product's life cycle. The stereotypes, which are indicated by the «Guillemet» brackets, specify the meaning of the used modeling elements in the activity diagram, i.e. «Activity» refer to the main process stages, «Resource» refer to the material and the studied product itself and the «GHG Emission» stereotype shows that the emissions from all stages are considered. Finally, the filled and the crossed circles are indicating the starting and the ending of the corresponding activities.

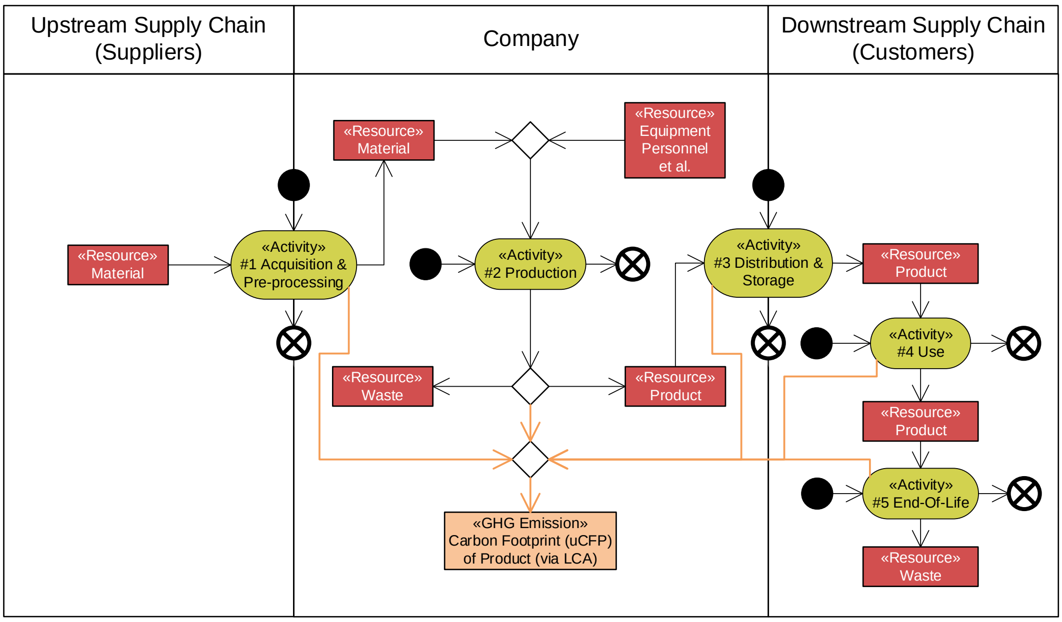

Figure 1: Assessment of GHG Emission over the Product Life Cycle (LCA) – Carbon Footprint of Product (uCFP)

2.2. GHG Protocol Requirement: Activity Based-Carbon FootPrint (AB-CFP)-Model

"The following equations illustrate how to calculate CO_2e for an input, output, or process based on activity data, emission factors, and GWP. More information on data collection and sources of emission factors are available in chapter 8. When process or financial activity data is collected, the basic equation to calculate CO_2e for an input, output, or process is:" (GHG Protocol, 2011, p. 88)

$$kg\ CO_2e = \underbrace{ActivityData}_{[unit]} * \underbrace{EmissionFactor}_{[kgGHG/unit]} * \underbrace{GWP}_{[kgCO_2e/kgGHG]} = \underbrace{uCFP_{act,fG}}_{[kgCO_2e]} \quad (1)$$

where

$uCFP_{act,fG}$	... unit Carbon Footprint, i.e. CFP per unit of product (*fG*) w.r.t. activity (*act*)
GWP	... Global Warming Potentials relative to CO_2
[*UOM*]	... Unit Of Measurement

"Activity data are the quantitative measure of a level of activity that results in GHG emissions. Activity data can be measured, modeled, or calculated. There are two categories of activity data: process activity data and financial activity data. Process activity data are physical measures of a process that results in GHG emissions or removals. These data capture the physical inputs, outputs, and other metrics of the product's life cycle. Process activity data, when combined with a process emission factor, result in the calculation of GHG emissions. Examples of process activity data include: Energy (e.g., Joules of energy consumed) [...] Financial activity data are monetary measures of a process that results in GHG emissions. Financial activity data, when combined with a financial emission factor (e.g., environmentally extended input-output [EEIO] emission factor), result in the calculation of GHG emissions." (GHG Protocol, 2011, p. 51).

The description of the conceptual AB-uCFP model in formula (1) clearly shows its generic structure as it does not provide a specific operationalization neither of the activity data nor of the emission factors. It only says that the activity data is quantified in units, where the unit of measurement [UOM] is not provided and accordingly can be selected as needed. This modeling flexibility carries over to the type of emission factor as the type depends on the activity data's UOM and accordingly is not yet specified as well.

3. GHG EMISSION MEASUREMENT: 3-LEVERS OF CONTROL-MODEL

Subsequently, the conceptual AB-uCFP model in formula (1) is operationalized by connecting it to activity data available in ABC costing systems so that it can consistently be used for practical AB-uCFP measurements. But before proceeding to this operationalization, the conceptual model is refined for building it upon an energy-based foundation.

3.1 2-LoEC-Model: Including Energy Resource View into AB-CFP-Model

The energy-based foundation of the conceptual AB-uCFP model provides a refinement that sharpens the focus, gives a solid common understanding and keeps substantial modeling flexibility at the same time.

(2) $$\underbrace{uCFP_{act,fG}}_{[kgCO_2e]} = \underbrace{EnergyConsumption_{act}}_{[kWh/unit]} * \underbrace{EmissionCoefficient_{act}}_{[kgCO_2e/kWh]}$$

where

act … activity
fG … finished Good

The energy-based foundation of formula (1) is shown in formula (2) where the activity data is now connected to the consumption of energy in the activity that is measured with a common kWh-UOM related to one unit of the studied product. It is also important to note that the term "unit" in formula (2) has a different meaning compared to formula (1): in (2) it relates to a single unit of the product, whereas in (1) it refers to the quantity in which the activity data is measured.
The refined conceptual uCFP model in formula (2) separates activity data from emission and GWP factors into "energy consumption" and "emission coefficient" that are connected via kWh as the common UOM for measuring energy. It is important to note that the delineation along the kWh-UOM does not restrict the focus on electric energy. Instead, it is a common and generic denominator for measuring energy in any type of activity. From a control perspective, the energy-based separation assigns the AB-uCFP measurement to two different control domains, i.e. the domain responsible for the energy consumption (e.g. production domain) and the domain responsible for the procurement of the energy. Accordingly, the refined conceptual model contains two levers of control, so that it constitutes a "2-Levers of Emission Control (2-LoEC)-model".
In the refined conceptual AB-uCFP model the term "emission coefficient" is used for expressing the special nature of the involved type of emission (GWP) factor. As its $kgCO_2e/kWh$ UOM indicates, the emission coefficient converts the amount of consumed energy measured in kWh into CO_2e, i.e. CO_2 equivalents. Consequently, in the refined conceptual model only one special type of emission factor is needed. The emission coefficient corresponds to the procurement control domain. In the case electric energy is procured for covering the activity's energy consumption the emission coefficient corresponds to the "grid emission factor" of the supplier of the electric energy.

3.2 3-LoEC-Model: Connecting AB-CFP-Model to Activity Based Costing (ABC)-Data

Now the refined conceptual GHG measurement model is operationalized by specifying the activity data involved in the activity's energy consumption. Analogously to the ABC costing methodology this specification corresponds to the identification of drivers which relates in the AB-uCFP context to the energy consumption. In the Time Driven (TD)-ABC methodology from Kaplan/Anderson (2007) the "unit-time" is used as the activity's key resource driver. In formula (3) the unit-time form the TD-ABC dataset, i.e. the time needed in the activity for producing one unit of the product is taken as the energy consumption driver. In the simplest case the energy consumption is calculated by multiplying the unit-time measured in hours [time/unit (h)] with the power coefficient [kW], i.e. the power level applied during the activity's consumed unit-time.

$$\underbrace{uCFP_{act,fG}}_{[kgCO_2e]} = \underbrace{d_{act,res,fG}}_{[time/unit\ (h)]} * \underbrace{p_{act,res,fG}}_{[kW]} * \underbrace{e_{res,scope,ghg}}_{[kgCO_2e/kWh]} \quad (3)$$

where

d	... **production coefficient** (unit-input) measured via unit-time [time/unit]
p	... **power coefficient** [kW]
e	... **emission coefficient** [$kgCO_2e$/kWh]
res	... economic resource
scope	... direct emission (scope 1) and indirect emission (scope 2 and 3)
ghg	... greenhouse gas

In formula (3) the energy consumption is decomposed into the two parts, i.e. firstly, the unit-time (d) needed in the activity (act) for producing the product (fG) by applying e.g. an equipment resource (res) and secondly, the power level (p) applied in the activity over the unit-time. This splitting of the energy consumption into its driver and the applied power introduces two different levers of control, so that the operationalized AB-uCPF model in formula (3) constitutes a "3-Levers of Emission Control (3-LoEC)-model".

The 3-LoEC-model in formula (3) operationalizes the refined conceptual AB-uCFP model via three levers of control that are expressed in terms of the models three coefficients, i.e. the production coefficient that measures the unit-input (e.g. unit-time), the power coefficient that measures the applied power level and the emission coefficient that converts the consumed energy into GHG emission. It is important to note that this operationalization is the simplest variant of a 3-LoEC-model. More advanced model variants can easily be developed by including multiple energy consumption drivers. E.g., in an activity not only an equipment resource but also material and personnel resources might be used. Moreover, the unit-time-UOM of the driver is only adequate for activities where the energy consumption is mainly (exclusively) driven by time. This is not the case for transportation activities where time is inferior to e.g. mass and distance of the transported product. In this case a "unit-gram-meter-UOM" is more adequate.

An advanced variant of the 3-LoEC-model is also needed when further GHG reporting requirements have to be fulfilled. E.g., if GHG emissions have to be distinguished between direct (scope 1), indirect within the company (scope 2) and indirect along the up- as well as downside supply chain (scope 3) or different carbon footprint boundaries are considered like "Gradle to Grave", "Gradle to Gate", "Gate to Gate" or "Gate to Grave". For such measurement requirements adequate advanced 3-LoEC-models have to be established by including suitable energy consumption drivers and corresponding UOMs, suitable power coefficients and correctly aligned emission coefficients for all (aggregated) activities needed. This flexibility of 3-LoEC-modeling also allows the implementation of advanced concepts like the "Accounting for Climate Change" from Kaplan & Ramanna (2021).

4. GHG EMISSION REDUCTION AND MONITORING: GHG EMISSION-MCS

The AB-uCFP measurement and reporting of the actual GHG emission is not the only requirement from CSRD and ESRS E1. Additionally, the GHG emission reduction objective as well as information concerning the implemented GHG emission-management control systems and monitored objective achievements have to be reported.

4.1 X-Management Control System (X-MCS): Plan/Do/Check/Act-Cycle with related information flows

The 3-LoEC-model is suitable not only for measuring the actual uCFP and identifying emission reduction potentials. Instead, it also can be used for activity-based forecasting as well as activity-based budgeting of future GHG emissions and thereof derived GHG emission reduction objectives.

$$CFP^{bud} = \sum_{act} \sum_{fG} uCFP^{bud}_{act,fG} * x^{bud}_{fG} \quad (4)$$

where

CFP^{bud}	... budgeted CFP over all manufactured products (*fG*)
$uCFP^{bud}_{act,fG}$	... budgeted CFP for activity *act* of product *fG*
x^{bud}_{fG}	... budgeted production units of product *fG*

Formula (4) shows the calculation of the budgeted CFP for all manufactured products via multiplying the budgeted uCFP with the budgeted production units and summing the results over all manufactured products and all therefore needed activities.
For being able to report on the implemented GHG emission-management control systems it is advisable to refer to the ISO 14.000 environmental management system standard family. The working of such a management system can be seen in the management activity diagram (MAD) visualization shown in

Figure 2. The four activities of the Plan/Do/Check/Act (PDCA) cycle are depicted as stereotyped rounded rectangles together with the measurement activity («Measure»). The information flow between the different activities relate to the rectangles. The thereby stereotyped information specifies its meaning.

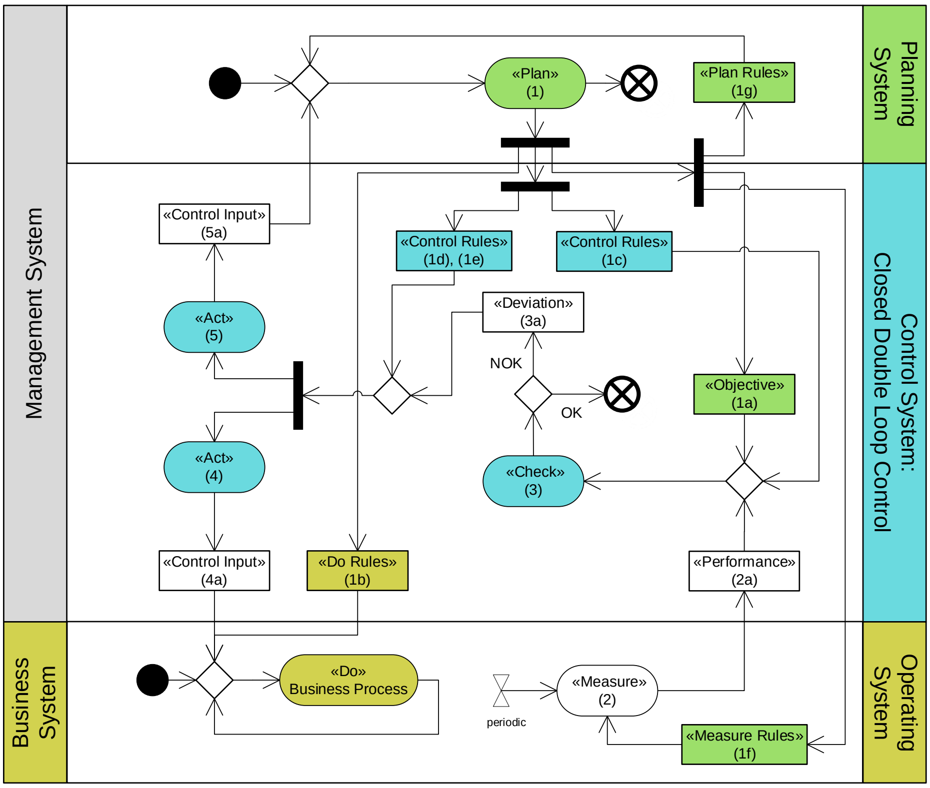

Figure 2: X-Management Information System (MIS) – Management Activity Diagram (MAD)-Model

"One of the fundamental principles is that all the standards can work together. Those who already use an MSS in one part of their business, and are considering implementing additional ones in another area, will find that the process has been made as intuitive as possible. That's thanks to the Harmonized Structure (HS). The concept of HS is that management standards are structured in the same way, regardless of the domain of application. Users who are familiar with one MSS will immediately feel at ease with another, even when using if for the first time." (ISO Management System Standards 2023 as well as 2023a, 2023b).

4.2 GHG Emission-MCS: Planning and Control of GHG Emission Performance

The management activity diagram in Figure 2 is a template into which the activities and related information flows of the environmental management system can be inserted. In Figure 3 this contextualization is summarized by describing the contents of the different activities and related information flows. The interpretation starts with the Plan activity (1), where among others the "Reduction of GHG emission" objective (1a) and the "Use 3-LoEC-model for measurement" measurement rule (1f) are specified. Over time the Do rules (1b) are executed in the Do activity and the performance measure "GHG emission" (2a) is assessed in the measure activity. In the Check activity (3) the measured GHG emission performance is compared with the GHG reduction objective. If the objective is not achieved the resulting deviation (3a) triggers two adjustments. In the corrective Act activity (4) the Do activity is instructed to "reduce waste by lowering operating power level" (4a) and in the adaptive Act activity (5) the Plan activity (1) is requested to "rethink the plausibility of the required reduction objective" (5a). Due to the two adjustment loops this system is a "closed double loop control system".

	GHG-Management Control System
(1) PLAN-Activity	
(1a) Objective	Reduction of GHG emission
(1b) DO-Rules	Operate equipment
(1c) CHECK-Rules	Compare actual to budget emission
(1d) Corrective ACT-Rules	Improve equipment performance
(1e) Adaptive ACT-Rules	Adjust reduction objective
(1f) Measure-Rules	Use 3-LoEC-model for measurement
(1g) PLAN-Rules	Alignment with GHG Protocol requirements
(2) Measure-Activity	
(2a) Performance Measure	GHG emission
(3) CHECK-Activity	
(3a) Deviation	Deviation from reduction objective
(4) Corrective ACT-Activity	
(4a) Closed Loop Control Input	Reduce waste by lowering operating power
(5) Adaptive ACT-Activity	
(5a) Closed Loop Control Input	Rethink plausibility of reduction objective

Figure 3: GHG Emission-Management System – Demonstration Case

An PDCA-based environmental management system is the "diagnostic management control system" in the "4-Levers of Control" framework of Simons (1995). A comprehensive analysis of applications of the 4-LoC-framework in the context of environmental management systems is provided by Beusch et al. (2022).

5. CONCLUSIONS

The primary research object is the design of an operationalized AB-uCFP-model that firstly, is consistent with the legal requirements coming from the CSRD and ESRS E1 and the thereby referenced GHG Protocol standards, secondly, is built upon a common information system that puts different management control domains on a shared information basis, and thirdly, is usable for practical implementations related to reporting and management control issues. This objective was achieved in two steps, i.e.

- by starting from the conceptual GHG Protocol measurement methodology and designing from there a refined conceptual AB-uCFP model by placing the original conceptual model upon an energy-based foundation and
- by operationalizing the refined conceptional model with respect to a shared base of activity data and publicly available emission factors.

Accordingly, the research objective is achieved as the designed 3-LoEC-model solves all three above mentioned criteria connected to the objective's underlying alignment problem. The advantages derived from the 3-LoEC-model can be summarized as follows: it measures the uCFP via three levers of emission control that are related to the consumption and procurement of energy, it is connected to data contained in ABC systems, and it is a forecasting instrument as well so that it is at the core of the activity-based GHG emission budgeting and the corresponding MCS with respect to GHG emission.

For demonstrating the practical applicability of the 3-LoEC-model this paper ends with this simple use case example. Imagine, for manufacturing a product an electric equipment resource is applied that operates 1 hour (unit-time as production coefficient) under full power of 10 kW (production coefficient). This gives an energy consumption of 10 kWh. Imagine furthermore, according to an energy supply shortage this energy can only be procured from a brown coal operated power plant. In this worst-case scenario the emission coefficient amounts to 1.188 $kgCO_2e/kWh$. According to formula (3) this gives a uCFP of uCFP = 11.88 $kgCO_2e$. As already its name suggests, the 3-LoEC-model contains three levers for controlling the uCFP, i.e. the production coefficient in form of the unit-time, the power coefficient in form of the applied power level and the emission coefficient in form of the grid emission factor. All three levers can be used to mitigate and especially reduce the uCFP. Finally, if for the next year controls were identified that – when implemented – reduce the uCFP by 0.688 $kgCO_2e/kWh$, the GHG emission reduction objective for a budgeted 10 product units amounts to 6.88 $kgCO_2e/kWh$. In order to achieve this objective, the rules for the PDCA activities in the GHG emission-MCS are specified and – of course – executed accordingly.

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